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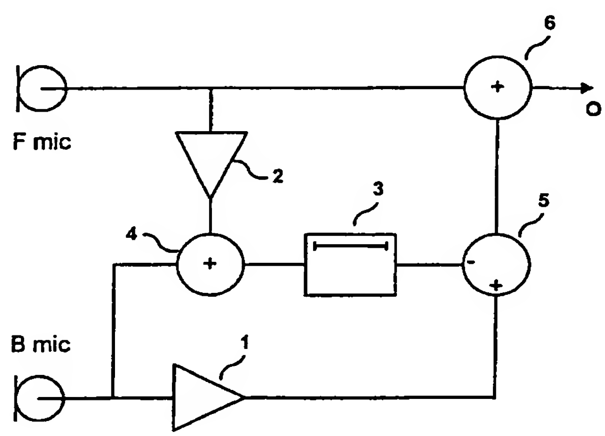
(54) Title: HEARING AID WITH CONTROLLABLE DIRECTIONAL CHARACTERISTICS



(57) Abstract: The invention relates to a hearing aid with a controllable directional characteristic, having at least two spaced apart first and second microphones (Fmic, Bmic), at least one signal processing unit, at least one output transducer and a directional controller including at least one delay device for delaying the output signal from at least the second of said at least two microphones to be combined with the undelayed output signal from at least one other microphone, the directional controller comprising adding or combination means (4, 5, 6) and at least a first attenuator means (1) for processing the output signal of said second microphone (Bmic), generating a first processed signal to be added by said adding means (5, 6) to the output signal of said first microphone (Fmic), further comprising at least a second attenuator means (2) to operate on the output signal of said first microphone (Fmic) for generating a second processed signal to be combined with the output signal of said first microphone (Fmic) by said adding means (4, 5, 6) wherein the directional controller comprises at least a delay device (3) inserted into the signal path of the second processed signal before it is added in the adding means (5, 6).

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Hearing aid with a controllable directional characteristic

The present invention relates to a hearing aid with a controllable directional characteristic, which may change from an omnidirectional to a directional characteristic and vice versa in accordance with the preamble of claim 1.

Background of the invention

Directional hearing aids are useful to improve the speech perception in highly noisy environments, such as parties and the like.

The directional hearing aid improves the speech perception by reducing the reception of sound coming from the back of the user, whereas sound coming from the area in front of the user is not reduced.

In environments with only a low noise level or with no significant speech signals it is normally preferable to have an omnidirectional characteristic of the hearing aid. Therefore, it would be quite practical and also desirable to have hearing aids that could adapt or change its directionability from a directional pattern to an omnidirectional pattern to be useful in noisy environments and in more quiet environments as well. Hearing aids of this type are generally known.

If in a hearing aid of this type the directional characteristic is changed or changes from non-directional to directional, the arrival time of the sound changes during the transition. This change of phase or time delay may become confusing in a binaural hearing aid system using a pair of separate hearing aids operating with independent and automatic change of the directional characteristic. When phase and arrival times change differently in the two hearing aids this will degrade or deteriorate the users ability to locate the various sound sources in the surrounding space and the advantages of a binaural hearing aid system will be degraded.

Furthermore,the phase and time relationship in a hearing aid degrades the quality of the sound perceived by the user. It may then sound like the result of a Doppler-effect.

Hearing aids of this type usually will also change the amplitude characteristic from a flat response to a response in which the amplitudes of higher frequencies will be increased. This increase may be in the area of 6 dB/octave. This results in a serious problem, because hearing aids of this type can not be perfectly fitted with an optimum transfer characteristic for both the non-directional and the directional characteristic.

This is, therefore, an object of the present invention to design a hearing aid, in which a change from an omnidirectional pattern to a directional pattern could be effected as a switchover of as a smooth changeover, without a change in the phase relationship or the time delay and with little or no effect on the amplitude characteristic of the signals. Such a change from an omnidirectional characteristic to a directional characteristic and vice versa should be controlled or be controllable or may even be automatic.

For such an automatic control of the directional characteristic of a hearing aid one could possibly use specific circuitry detecting or ascertaining the prevailing noise level and its sructure in the frequency domain in the environment surrounding the user. Also it would be advantageous if, after the circuitry effecting the change in the directional characteristic of the hearing aid, the character of the background noise could be evaluated in order to minimize the resulting noise, particularly for maximazing the signal-to-noise ratio.

Summary of the invention

These objects of the present invention may be achieved in a hearing aid with a controllable directional characteristic, having at least two spaced apart first and second microphones, at least one signal processing unit, at least one output transducer and a directional controller

including at least one delay device for delaying the output signals from at least the second of said at least two microphones to be combined with the undelayed output signal from at least one other microphone, the directional controller comprising adding or combination means and at least a first attenuator means for processing the output signal of said second microphone, generating a first processed signal to be added by said adding means to the output signal of said first microphone, further comprising at least a second attenuator means to operate on the output signal of said first microphone for generating a second processed signal to be combined with the output signal of said first microphone by said adding means.

It is of particular importance that the directional controller comprises at least a delay device inserted into the signal path for the second processed signal before it is added in the adding means, and also that there are at least first, second and third adding means included, and that, where possible, the first and second adding means are combined into a single combination or adding means, and/or the second and third adding means are combined into a single combination or adding means.

Additional features and advantages of the present invention will become apparent from the remaining claims in conjunction with the description of the attached drawings.

Brief description of the drawings

In the drawings

Fig. 1 shows a schematic arrangement of the front end of a hearing aid including a directional controller;

Fig. 2 shows a similar schematic arrangement of the front end of a hearing aid including a directional controller preceded by signal processing units;

Fig. 3 shows a similar schematic arrangement of the front end of a hearing aid with a further embodiment of the directional controller, including a control unit and

Fig. 4 schematically shows a further improvement of the arrangement of Fig. 1.

Detailed description of the invention

Fig. 1, in principle, shows the front end of a hearing aid including a directional controller for changing the directionality of the hearing aid from an omnidirectional to a directional characteristic and vice versa. This change may be effective in a switch fashion or as a gradual and smooth changeover.

The front end of the hearing aid contains at least two microphones, i.a. a front microphone Fmic and a back microphone Bmic. The distance between the two microphones may be as small as 1mm or as wide as a few cm.

The front end further contains at least two controllable amplifiers or attenators 1 and 2, at least one delay device 3 and at least three adding means or summing circuits 4, 5 and 6. It is to be understood that the adding means or summing circuits may contain positive as well as negative input terminals.

In the structure, the back microphone Bmic is connected to the controllable amplifier or attenuator 1 and to said first adding means or summing circuit 4.

The front microphone Fmic is connected directly to the controllable amplifier or attenuator 2 and to the adding means or summing circuit 6. The output of the controllable amplifier or attenuator 2 is directly connected to a second input of adding means or summing circuit 4, whereas the output of the controllable amplifier 1 is directly connected to a positive input of adding means or summing circuit 5. Between the output of the adding means or summing circuit 4 and a negative input of adding means or summing circuit 5 a preferably controllâble delay device 3 is included.

In the following description the adding means or summing circuits will generally be designated as summing circuits, although some of them may, with their negative inputs perform subtractions.

In operation, the sound environment is picked up both by the front microphone Fmic and the back microphone Bmic. The distance between the two microphones may be as small as 1mm and as wide as a few cm.

The output signal of the front microphone Fmic is directed to the summing circuit 6. The output signal of the back microphone Bmic is directed to the controllable attenuator or controllable amplifier 1, the amplification of which may be controllably changed from zero to one, i.e. from no amplification to full amplification. This changeover may be effected as a switching over or as a controlled gradual change. This means that any amplification between zero and one may be controllably achieved.

The output signal, if any, of the front microphone Fmic is also connected to a controllable attenuator or amplifier 2, the amplification of which may controllably be changed from zero to one, i.e. from no amplification to full amplification. Also in this case this changeover may be effected as a switching over or as a gradual controlled change. This means that any amplification between zero and one may be achieved,

The output, if any, of the controllable attenuator or amplifier 1 is connected to a second input of the summing circuit 4. The output signal, if any, of summing circuit 4 is applied to a controllable delay device 3, the delay of which may be controlled from as small as 1us up to 1000 us or higher.

This output signal, if any, of delay device 3 is applied to the second input of summing circuit 5, the output of which is applied to the second input of the third summing circuit 6.

Thus, for instance, the output signal of the front microphone Fmic may then be attenuated in attenuator or controllable amplifier 2 before it is added to the undelayed output signal of the back microphone Bmic in the summing circuit 4, the output signal of which is then delayed further in delay device 3 before being applied to the summing circuit 5. The controllable delay of delay device 3 usually will have the same delay that exists as an acoustical delay between the arrival times of sounds at the front microphone Fmic and at the back microphone Bmic. Preferably this delay is also adjustable and/or controllable.

Additionally, the output signal of the attenuator or controllable amplifier 1 is applied to the first input of the second summing circuit 5. In this summing circuit the delayed output signal of delay device 3 is subtracted from the attenuated output signal of amplifier 1. The output signal of the summing circuit 5 is applied, as a processed signal to the summing circuit 6. The output signal of the summing circuit 6 is then used as an input signal for further processing in the remaining components of the hearing aid, which need not to be described here.

Of course, the remaining parts of the hearing aid could comprise more than one channel, having one directional controller in common or one for each channel
It is preferable to convert the output signal of both microphones Fmic and Bmic to a digital representation before applying them to the directional controller with its components 1 to 6.

Fig. 2 shows a similar circuit for a front end of a hearing aid including a directional controller with the components 1 to 6. Similar components have been assigned the same reference numerals.

Additionally, signal processing units 7 and 8 are placed at the outputs of the at least two microphones, i.e. the front microphone Fmic and the back microphone Bmic. The processed output signals of the two signal processing units 7 and 8 are then applied to the directional controller with components 1 to 6. The signal processing units 7 and 8 may perform

an equalizing function on the two output signals of the two microphones and/or may contain various filters, f.i. band pass filters. With the use of band pass filters the microphone signals may be split up into several bands, each equipped with its own directional controller. The respective output signals from the different summing circuits 6 may then be combined into a composite output signal to be further processed in the remaining stages of the hearing aid.

Fig. 3 shows a similar circuit as in Fig. 1 and 2, so that for the same components the same reference numerals are used. In this circuit the time delay for both output signals of the two microphones Fmic and Bmic is performed in separate delay units 3a and 3b representing the delay device 3. Otherwise, the function is similar to the function of the circuits of Fig. 1 and 2. Furthermore, a control unit 9 is shown, which may control the attenuation of the controllable amplifiers 1 and 2 as well as the delays of delay units 3a and 3b. This embodiment of the invention is of special advantage in combination with microphone input circuits, which are capable of applying a delayed microphone signal together with an undelayed microphone signal for a hearing aid. Such a circuit has been disclosed and described in the copending PCT-Application PCT/EP 99/00767 of the same applicant/assignee as the present application.

As has been stated at the beginning, it is of great importance that, in the directional controller, the spectral intensitiy as well as the time and phase of the audio signals are not changed when their directivity changes.

Fig. 4 schematically shows a further improvement of the front end of a hearing aid including a directional controller asdescribed so far with respect to Fig. 1. Similar components have been designated with the same reference numerals as before.

Because of the technique used in combining the output signals of the two microphones Fmic and Bmic, the resulting amplitude response of the output signals of the adding means 6 will - of course - in the relevant frequency range - rise with 6 dB per octave in relation to the amplitude response of a single microphone .

This behaviour may be observed in all systems subtracting a delayed version of the output signal from the back microphone from the undelayed output signal from the front microphone, while achieving a directional effect.

However, in most cases, it is desirable to compensate for this change in the amplitude response by adding a filter at the output of the front end of the hearing aid, i.e. at the adding means 6. Such a filter, of course, means a reduction of 6 dB per octave in the relevant frequency range. The drawback of such a solution would be that more real estate,time and power would be required, all of which are of very crucial importance in modern hearing aid technology.

However, the directional controller of the present invention could also be made to perform this compensation filtering. Therefore there will be no need to add a filter at the output of adding means 6.

For this purpose an additional adding means 10 is installed between adding means 4 and delay device 3. The additional adding means 10 has a positive input, a negative input and an output.

The output of adding means 6 is directly applied to the negative input of adding means 10 in a feedback loop.

This new arrangement has already the desired effect.

It may be preferable to include a controllable amplifier or attenuator 11 into the feedback loop.

Thus, the output signal of the directional controller is fed back from adding means 6 to the controllable amplifier or attenuator 11 and to the negative input of adding means 10. Thus, the output signal of amplifier or attenuator 11 is subtracted from the output signal of adding means 4 in the adding means 10.

The resulting output signal of adding means 10 is applied to the delay device 3 and hence to the negative input of adding means 5, the positive

input of which is connected to the output of the controllable amplifier or attenuator 1.

In principle, in all embodiments of the invention, adding means 5 and adding means 6 could also be combined into one unit, provided the combination device has, in every respect, the same properties as the two separate adding means 5 and 6.

Ideally, the gain factor of attenuator 11 should be one or unity for the filtering being able to perform the 6 dB per octave fall at very low frequencies. However, this would probably result in a loop gain of unity so that the circuit might become unstable. Therefore, it is preferable to have the gain of the amplifier or attenuator 11 set to a little less than one or unity.

Referring again to Fig. 1 the function of this circuit of a front end of a hearing aid with a directional controller is as follows:

For the directional mode of operation the signal transfer of the controllable amplifiers 1 and 2 is set at zero, i.e. no signal is transferred.

The output signal of the front microphone Fmic is directly applied to the third summing circuit 6. The output signal of the back microphone Bmic is applied via the first summing circuit 4 and delay device 3 to the negative input of the second summing circuit 5, where the signal changes its polarity. The output signal of the summing circuit 5 is then applied to a second input of the third summing circuit 6. Thus, the delayed signal from the back microphone Bmic is subtracted from the

undelayed output signal of the front microphone Fmic.

The directional front characteristic may then be created by adjusting the delay T of the delay device to be the same as the acoustical delay A between the back microphone Bmic and the front microphone Fmic. With this delay the signals that are first received at the back microphone Bmic and are later received at the front microphone Fmic are then suppressed in the summing circuit 6, where the delayed signal of the back microphone is subtracted from the output signal of the front microphone.

This mode of operation results in an output signal from summing circuit 6 which is the result of the addition of the output signal of the front microphone Fmic, minus the delayed output signal of the back microphone Bmic, thus cancelling sound coming directly from the back of the user.

By adjusting $T < A$, sound coming partly from the side of the user is cancelled, the direction of the cancelling effect is controlled by the ratio of T/A.

For the omnidirectional mode of operation both amplifiers 1 and 2 are set for a full signal transfer.

The output signals from the front microphone Fmic and the back microphone Bmic are applied to the first summing circuit 4, where they are combined and applied via delay device 3 to the second summing circuit 5, where the combined and delayed signal is subtracted from the output signal of the back microphone Bmic.

The output signal of the summing circuit 5 is then applied to the third summing circuit 6 where it is combined with the undelayed output signal of the front microphone Fmic. The addition of these signals creates a nondirectional pattern or characteristic. This mode of operation results in an output signal from the summing circuit 6 which is generated by the addition of the signals from the front and back microphones from which the delayed front and back microphone signals are subtracted.

The sound signals received at the two microphones differ with respect to their arrival time at the respective microphones from a source, the distance of which is different for the two respective midrophones.

This difference is the acoustical delay A and the received sound signal may be generally expressed as

$$X_{back} = X_{front} * e^{-j\omega A}$$

Where: X_{back} is the acoustical sound received at the back microphone.

X_{front} is the acoustical sound received at the front microphone.

$e^{-j\omega A}$ is the acoustical delay for the actual direction of the sound source.

The combined signal Y from summing circuit 6 is

$$Y = X_{front} * (1 - omni * e^{-j\omega T}) + X_{front} * e^{-j\omega A} * (omni - e^{-j\omega T})$$

Where: omni is a value in the range from 0 to 1.

Omni = 0 is equal to no signal through the amplifiers 1 and 2.

Omni = 1 is equal to max. signal through the amplifiers 1 and 2.

if the full directional mode of operation is chosen with omni = 0, then Y becomes

$$Y = X_{front} * (1 - e^{-j\omega(A+T)})$$

If the delay T is selected equal to the delay A directly from the back microphone to the front microphone in the directional mode of operation, then the part of the sound signal X comming directly from the back of the user is suppressed to the maximum extent and a directional characteristic known as a cardoid characteristic is achieved.

The signal process described so far is preferably performed as a digital process in the time or frequency domain. If processing in the frequency domain ia employed it is advantageous to use microphone circuits which are capable of generating a delayed microphone output signal in combination with a non-delayed microphone output signal. Such microphone circuits are described in the copending PCT-Application (PCT/EP 99/00767) of the same assignee of the present application.

The microphones to be used are preferably omni-directional microphones.

When two microphones are used with the omni-directional mode of operation, both microphones generate an electrical noise signal N. These two noise signals have a similar power:

$$|N_{back}| = |N_{front}|$$

Where: N_{back} is the noise signal from the back microphone.

N_{front} is the noise signal from the front microphone Fmic.

The noise signals N are random signals. Therefore, the resulting signal amplitude is less than twice the single amplitude. Thus, a 3 dB-noise reduction results. The total noise signal can be calculated as:

$$|N|^2 = |N_{front}|^2 * \left|1 - omni * e^{-j\omega T}\right|^2 + |N_{back}|^2 * \left|1 - omni * e^{-j\omega T}\right|^2$$

=>

$$|N| = |N_{front}| * 2^{1/2} * \left|1 - omni * e^{-j\omega T}\right|$$

It has been shown that with the new front end of a hearing aid comprising a directional controller in accordance with the invention a great variety of directional patterns may be controllably realized.

PATENT CLAIMS

1. Hearing aid with a controllable directional characteristic, having at least two spaced apart first and second microphones (Fmic, Bmic), at least one signal processing unit, at least one output transducer and a directional controller including at least one delay device for delaying the output signals from at least the second of said at least two microphones to be combined with the undelayed output signal from at least one other microphone, the directional controller comprising adding or combination means (4, 5, 6) and at least a first attenuator means (1) for processing the output signal of said second microphone (Bmic), generating a first processed signal to be added by said adding means (5, 6) to the output signal of said first microphone (Fmic), further comprising at least a second attenuator means (2) to operate on the output signal of said first microphone (Fmic) for generating a second processed signal to be combined with the output signal of said first microphone (Fmic) by said adding means (4, 5, 6).

2. Hearing aid in accordance with claim 1, characterized in that the directional controller comprises at least a delay device (3) inserted in the signal path for the second processed signal before it is added in the adding means (5, 6).

3. Hearing aid in accordance with claim 1 or 2, characterized in that said adding or combination means comprises at least a first adding means (4), a second adding means (5) and a third adding means (6)

4. Hearing aid in accordance with claim 3, characterized in that said first and said second adding means are combined into a single combination or adding means, and/or said second and said third adding means are combined into a single combination or adding means.

5. Hearing aid in accordance with claim 3 or 4, characterized in that a second input of said first adding means (4) is connected to the said second attenuator means (2) for receiving said second processed signal to be combined with the output signal of said second microphone (Bmic), and to be further combined with the said first processed signal in said second adding means (5), the output signal of which is connected to one input of said third adding means (6) to be combined with the output signal of said first microphone (Fmic).

6. Hearing aid in accordance with claims 3 to 5, characterized in that the directional controller comprises at least a delay device (3) inter-connected between the first adding means (4) and the second adding means (5) to delay the second processed signal before it is combined in adding means (6) with the output signal of said first microphone (Fmic)

7. Hearing aid in accordance with claim 1 or 2, characterized in that the first attenuator means (1) to operate on the output signal of said second microphone (Bmic) comprises a controllable attenuator means (1).

8. Hearing aid in accordance with claim 1 or 2, characterized in that the second attenuator means (2) to operate on the output signal of said first microphone (Fmic) comprises a controllable attenuator means.

9. Hearing aid in accordance with claim 7 or 8, characterized in that for said controllable attenuator means a controllable amplifier is provided.

10. Hearing aid in accordance with claims 7 or 8, characterized in that for controlling the said controllable attenuator means (1, 2) a control unit (9) is provided.

11. Hearing aid in accordance with claims 1 to 5, characterized in that the delay of the delay device (3) is controllable by means of said control unit (9).

12. Hearing aid in accordance with claim 2, characterized in that the said delay device consists of two separate delay units (3a, 3b) operating on the ouptut signal of said at least first and second microphone, respectively, delaying the input signals to said adding means (5) and to the said second attenuator means (2) respectively, the ouptut signal of which is also applied to said adding means (5).

13. Hearing aid in accordance with claims 1 to 6, characterized by a feedback loop connecting the output of said third adding means (6) to a negative input of an adding means (4; 10) arranged in front of said delay device (3).

14. Hearing aid in accordance with claim 13, characterized in that said adding means (4) is equipped with a further negative input, the feedback loop being connected to said further negative input of said first adding means (4).

15. Hearing aid in accordance with claim 13, characterized in that in addition to said adding means (4) an additional adding means (10) is provided and arranged in front of said delay device (3) and having a positive input, a negative input, and an output, the feedback loop being connected to the negative input of said additional adding means (10).

16. Hearing aid in accordance with claims 13 to 15, characterized in that an additional attenuator (11) is included in said feedback loop.

17. Hearing aid in accordance with claim 16, characterized in that the gain of said attenuator means (11) is somewhat less than unity.

18. Process of operation in a hearing aid with a controllable directional characteristic, the hearing aid having at least two spaced apart microphones, at least one signal processing unit, at least one output transducer and a directional controller including at least one delay device for delaying the output signals from at least the second of said two microphones, and at least adding or combining means for combining the delayed output signals from at least said second microphone with the undelayed output signals from at least the first of said two m icrophones, the process comprising the following steps:
   a) attenuating the output signals from said second microphone for generating the first processed signal,
   b) combining said attenuated output signal from said second microphone with the undelayed output signal of said first microphone,
   c) generating a second processed signal by attenuating the output signals from said first microphone and
   d) combining said second processed signal with the undelayed output signal from at least said first microphone.

19. Process according to claim 18, characterized by the additional steps:

   c2) generating a second processed signal by attenuating and delaying the output signals from said first microphone and

d2) combining said second processed and delayed output signal of said first microphone with the undelayed and unprocessed output signal of said first microphone.

20. Process in accordance with claims 18 to 19, characterized by controlling the attenuation and/or the delay in said attenuator means and said delay device to obtain a desired directional characteristic.

21. Method in accordance with claims 18 to 19, characterized by the following steps:
   a) feeding back the output signal of said directional controller to the input of said delay device, subtracting it from the output signals of said adding means, delaying the resulting signal in the delay device and combining said delayed signals with the undelayed output signal of said first microphone.

22. Process in accordance with claim 21, further characterized by the step:
   f) attenuating the output signal of the directional controller before applying it to the negative input of said additional adding means.

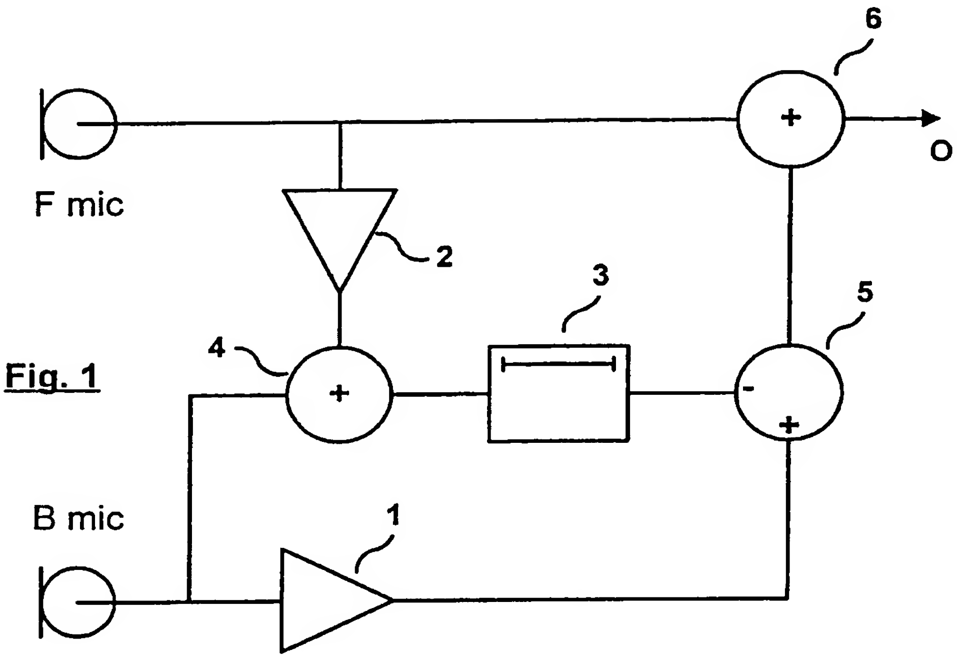

Fig. 1

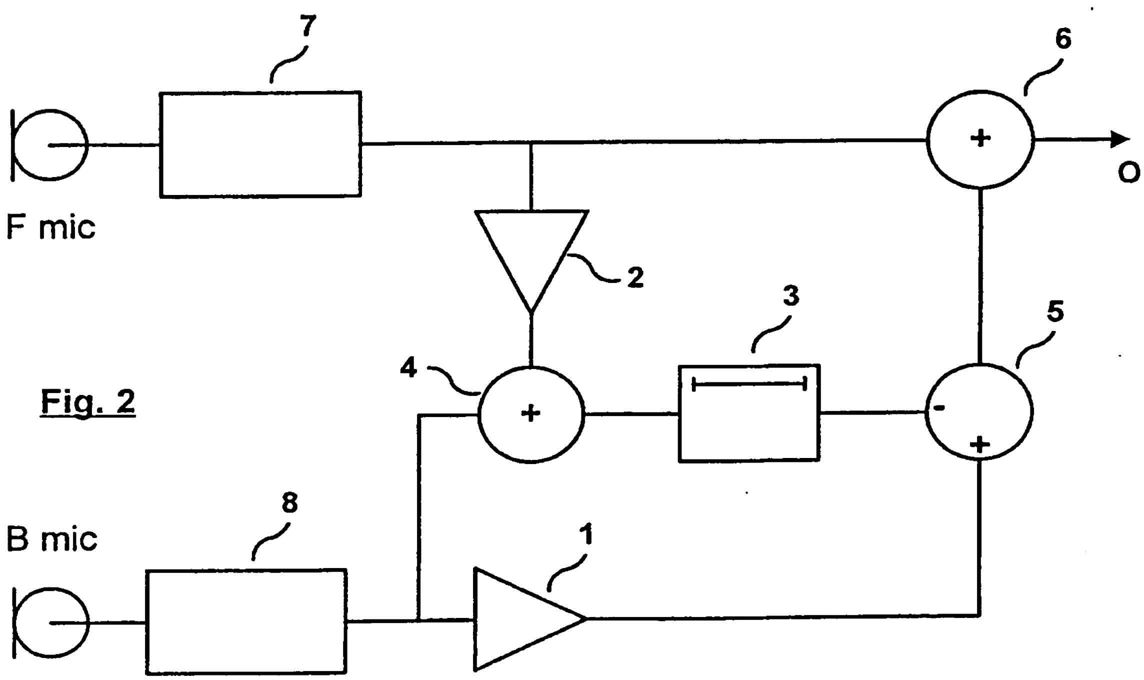

Fig. 2

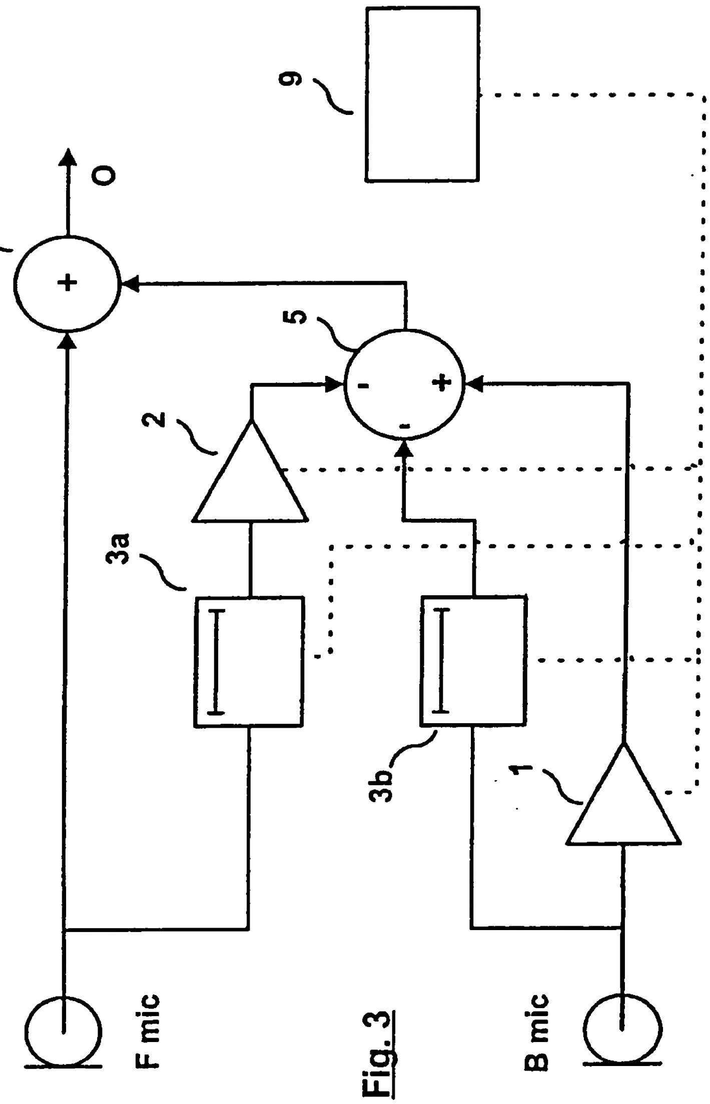

Fig. 3

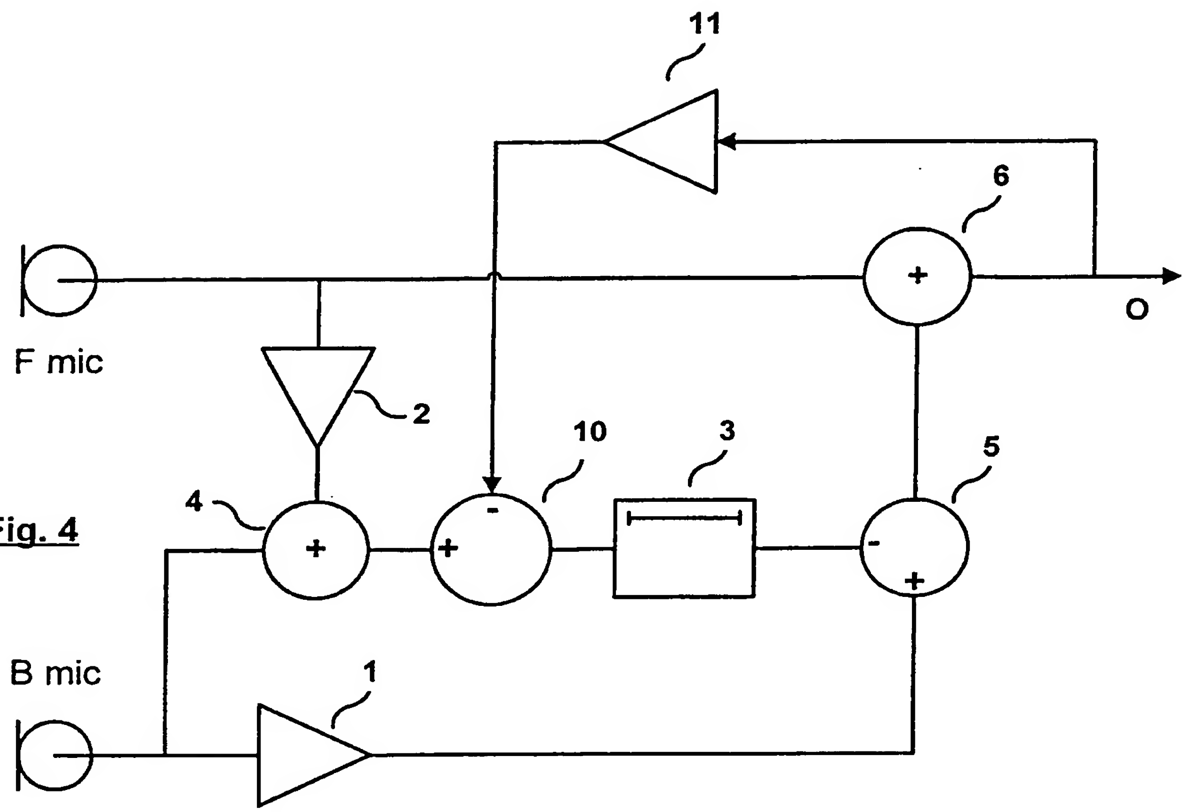

Fig. 4

INTERNATIONAL SEARCH REPORT

Inte. ..ional Application No
PCT/EP 99/04375

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04R25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04R H03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 757 933 A (PREVES ET AL.) 26 May 1998 (1998-05-26) column 1, line 5-11	1-11,13, 18-20
A	column 2, line 29 -column 3, line 39 column 4, line 43 -column 7, line 13	12, 14-17, 21,22
Y	EP 0 466 676 A (VIENNATONE) 15 January 1992 (1992-01-15) page 2, line 1,2	1-11,13, 18-20
A	page 2, line 18-34 page 3, line 9-17	14-17
A	US 5 033 090 A (WEINRICH) 16 July 1991 (1991-07-16) column 2, line 4 -column 4, line 39	1-22

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
2 March 2000	09/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Zanti, P

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 99/04375

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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